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THE COMMERCIALIZATION OF THE

GLOBAL POSITIONING SYSTEM

A Research Paper

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by

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Disclaimer

The views expressed in this academic research paper are those of the author(s) and do not reflect the official policy or position of the US government or the Department of Defense.

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Preface

The 1996 Presidential Decision directing the eventual removal the Global Positioning System's "selective availability" features sparked conflict in my mind. Did this signal the demise of military GPS? Had the civilian GPS manufacturers finally managed to steal GPS for themselves? Had national security interests crossed paths with potential profits and lost? It was in this light that I approached this research, and my conclusions were quite different from my expectations.

In acknowledgment of the contributions of others to this effort, I would like to thank my Faculty Research Advisor, Major Christopher Cook, USAF, for his patience and for providing a great "initial vector." For any tremendous insights contained herein, I gladly share the credit; for any errors I take the blame alone. Additionally, I continue to be amazed at the wealth of material available through the Air University Library, and at the patience of the staff. I am certain that I tested it.

Abstract

In April of 1973, a memorandum issued by the Deputy Secretary of Defense consolidated two experimental satellite navigation programs into one effort: The NAVSTAR Global Positioning System was born. After 22 years and $8 billion dollars, the system was finally declared fully operational in 1995.

In 1983, a Reagan Administration directive authorized civilian use of the system. Evidence, however, shows that civil access to GPS was intended all along. Since the Reagan decision, the civil market has grown exponentially, and is predicted to exceed $8 billion in the year 2000. By 1995 alone, civil users outnumbered military users by ten to one.

While civil access is permitted, its users are subject to an intentionally degraded signal called "selective availability" that restricts accuracy to 100 meters. Civil users resent the degradation policy and have resorted to *differential* GPS techniques to evade the accuracy restrictions. Some commercial providers claim their subscription services allow accuracies close to 45 centimeters. The Department of Transportation is also in the differential GPS business, providing maritime and aviation augmentations. By Presidential decision, selective availability will be removed within ten years.

Examining the Department of Defense's initial vision, the forces behind the granting of commercial access, and the current state of GPS implementation, the study attempts to determine the effects of commercialization on military use of the system. Has GPS

provided all the benefits its designers envisioned? Has civil access degraded its military utility, or has it actually enhanced its military role?

Considering these issues, it becomes apparent that the growth of GPS has seen tremendous cost reductions and innovation in applications of the technology. Although the growth of civil users has created some difficulties for DOD, civil access has actually enhanced DOD's ability to field the system and procure user equipment. By providing a large volume of demand, economies of scale and a force for innovation in user equipment, the civil market has allowed DOD to exploit the full potential of the system.

Chapter 1

Introduction

> *I must go down to the sea again, to the lonely sea and the sky, and all I ask is a tall ship, and a star to steer her by.*
>
> —John Masefield

Since the first time early man left familiar surroundings and ventured out into the unknown wilderness, the ability to navigate has been integral to his impact upon history. How many of the world's discoveries were possible only through the discovery of the compass? Further development of navigational instruments and techniques parallel the development of civilization, perhaps even substantially contributing to that development. From sextant to radio beacon to satellite fixing, navigational improvements have revolutionized man's conquest of his surroundings.

The latest development poised to revolutionize man's interaction with his environment is the Global Positioning System (GPS). Initially developed in the 1970's by the Department of Defense (DOD) to exponentially improve navigational capabilities of military users, President Reagan granted civil access to the signals in a 1983 decision.[1] Despite military concerns, commercial use expanded rapidly in the following years. With GPS information guiding commercial airliners, aiding surveyors, steering building construction, and switching high-speed networks, civilian users have become increasingly dependent upon the system.

This civilian dependence will likely lead to increasing conflict with military needs, creating a quandary for U.S. policy planners. DOD, considering GPS navigational accuracy a potential threat to national security interests, limits the accuracy available to civil users and reserves the right to further degrade or even deny its use in times of crisis. Civil users have countered the intentional signal degradation through innovative system enhancements providing even greater accuracy than that available to military users. In 1996, President Clinton promised to remove "selective availability" within ten years, further encouraging the widely-held belief that wartime denial of system information would be politically impossible.[2]

Fully operational after 22 years[3] and $8.1 billion,[4] DOD finally has its long awaited system. Does the system provide military users all they envisioned? Has civilian usage compromised its military utility, or has their usage actually enhanced its military role?

This study will examine these questions in substantial depth, limited only by the need to maintain an unclassified posture. In that respect, some potential DOD capabilities, plans, and analysis were not considered, and will not be discussed. Intended to be an analysis of policy, an intentional effort has been made to avoid an in-depth explanation of the electronic workings of the satellites or other associated "black box" components.

This paper will examine the development of GPS, including the potential benefits sought by the DOD, the granting and growth of commercial access, the forces and policies involved, and the system's current implementation in civil and military roles. Additionally, further discussion will examine the future military utility of the system, particularly in light of greatly increased civilian usage. As GPS represents perhaps the shining example of the proper management of "dual-use" technology, it is hoped that an increased understanding

of the complex interrelationship between military and civil demand will contribute toward optimization of future developmental initiatives, and allow DOD to fully exploit the potential of such leveraged procurement.

Notes

[1] Statement by the Principal Deputy Press Secretary to the President, 16 September 1983, in Scott Pace et al., *The Global Positioning System: Assessing National Policies* (Santa Monica, CA: RAND, 1995), 273.

[2] "US Reviews GPS Policy," *Military Technology*, May 1996, 8-9.

[3] Scott Pace et al., *The Global Positioning System: Assessing National Policies* (Santa Monica, CA: RAND, 1995), 246.

[4] Ibid., 267.

Chapter 2

The Promise of GPS

Throughout history, man has relied on external sources for navigation. Early navigators depended on compasses, chronometers and sextants to guide them on their journeys. Electronic navigation was first developed in the 1920's when radio beacons ashore were used to guide navigators at sea. Although man had depended upon celestial bodies for navigation for centuries, the exploitation of *artificial* celestial bodies, i.e. satellites, has only been a recent phenomena. This development is partially chronicled in Appendix A.

A 1967 Joint Chiefs of Staff study conducted a comprehensive study of all navigation systems currently in use or in development, primarily oriented toward seeking reduction in redundant capabilities while satisfying military requirements for position fixing. The multitude of systems in operation included OMEGA, LORAN, DECCA, TACAN, VOR/DME, and TRANSIT. Clearly some redundancies existed. The resulting JCS Master Navigation Plan concluded that a "a space-based navigation system would be most likely to fulfill established navigation requirements, and should be given priority to attain operational status as soon as possible."[1]

Early system advocates within the Department of Defense projected tremendous possibilities for such a system. To achieve the promised greater operational efficiency and

reduced costs, DOD needed an "advanced, multipurpose, weatherproof, jam-proof, super-accurate system that could serve the needs of most users and replace most of the existing equipment."[2] GPS promised to be exactly that.[3]

Increases in Operational Efficiency

In 1980 Congressional testimony, then-DOD Under-Secretary for Research and Engineering Dr. William J. Perry said GPS "will give the United States and its allies a truly revolutionary capability in navigation. It broadens the concept in navigation beyond what we thought of in the past."[4] Others said: "Imagine, if you will, a military operation without a patrol being 'lost,' with the artillery able to lay in its guns with uncanny speed and accuracy and to know exactly where the normally wayward mess truck is at all times. Fantasy?"[5] Not with GPS.

Defining "friction" and the "fog of war," Clausewitz said "Everything in war is very simple, but the simplest thing is difficult."[6] While not promising to free military commanders from friction altogether, GPS promised to provide substantial "lubrication." Navigation, positioning and synchronization errors have plagued military operations throughout history. Parachutists were dropped in the wrong places on D-day. Forces have been put ashore on the wrong beach.[7] Units have compromised operations by engaging prematurely due to faulty timing. Not only did GPS promise to eliminate these types of "friction," but it offered commanders the ability to coordinate the sort of complex maneuver operations previously thought impossible.

GPS also promised to increase both navigational and weapons system accuracy, thereby serving as a substantial force multiplier. With advocates predicting that GPS-

equipped weapons systems would achieve a tremendous increase in hit probability, the long sought "silver bullet" was potentially within reach:

> A 90-95% hit probability for a single missile can be expected. It means that an aircraft or ship does not have to fire several rounds at one target but that one shot suffices. This in turn increases the combat value of the launching platform because it can engage as many targets as it has missiles on board.[8]

Additionally, the coordination benefits resulting from all users referencing a common grid promised improvements in synchronization, fire support, and maneuver, with substantial reductions in fratricide.

GPS also promised to reduce platform vulnerability and improve tactical flexibility. Unlike active systems such as TACAN, VOR/DME, or radar navigation techniques, GPS position fixing would be a totally passive evolution with no telltale emissions compromising the user's position. Passiveness offered the added benefit of allowing an infinite number of users at any given time without system saturation.

In 1980, DOD Undersecretary Perry described the results of testing he had observed:

> We went for a night flight in a helicopter, and with only the GPS as a navigation aid, we made a blind landing at an airfield at night...landing within three to four feet of the X that was on the runway. Then we watched a C-141 guided only by the satellite and it parachuted to the ground supplies that landed within 30 feet. Finally, we saw a demonstration of blind bombing techniques. This is where F-4s were dropping conventional bombs within ten to twenty feet of the target guided only by the Navstar satellites.[9]

In the 1978 blind bombing test he described, a GPS equipped F-4J dropped six non-retarded Mk-82 500 lb. bombs from 10,000 ft at 300 knots, resulting in five of six bombs impacting within 10 meters of target center. The sixth bomb hit within 20 meters.[10] Clearly GPS was capable of fulfilling at least some of its promises.

Cost Avoidance

Perhaps a greater promise offered by GPS was the ability to provide substantial cost savings, both directly and indirectly. While the stated purpose behind the 1973 merger of the TIMATION and Project 621B programs was to improve weapon system effectiveness, an additional purpose of the GPS program was "to promote cost savings by eliminating some navigational systems and stopping the proliferation of new ones."[11] The 1973 program justification submitted by DOD identified systems intended to be replaced by GPS: TACAN, LORAN, TRANSIT, and OMEGA. A 1975 Institute for Defense Analysis study counted in excess of 200 separate models[12] of navigation receivers in the DOD inventory and suggested that DOD could save over $400 million (1975 dollars) yearly through elimination of such systems.[13] While this would not, by itself, pay the entire bill for GPS, it would comprise a substantial down payment.

DOD was fully aware of these potential cost savings. In 1978, the Under Secretary of Defense for Research and Engineering, testifying before a Senate subcommittee, stated that "A fully implemented program could achieve a net cost saving for military users of over $200 million per year" by making "a major reduction in the use of other, more specialized navigation systems."[14] A GAO report criticized these statements, however, saying DOD was unable to provide documentation to justify these claims.[15]

The true potential for GPS to achieve cost savings was through indirect cost avoidance. How much fuel consumption would be avoided through more accurate navigation by ships and airplanes? How much fuel would be saved through the reduction in aircraft weight achieved by replacing the components of four separate navigation systems with one unit? Would that decrease in weight mean greater performance in aerial

combat, and therefore less cost in aircraft and pilot attrition? How many aircraft, ships, vehicles and lives would be saved through reduced vulnerability and increased situational awareness? How many less bombs would need to be procured, stored, transported, and delivered if each bomb could indeed achieve a level-of-magnitude increase in accuracy? What would the savings be in logistic costs alone? Of course, these questions are impossible to answer definitively; the savings are nonetheless real.

Implementation

The 1975 IDA study calculated potential military GPS receiver procurement to be approximately 23,000 units.[16] In 1977 and 1978 Congressional testimony, DOD estimated the number of users to be 27,000.[17] These figures accounted for the need to equip nearly every ship, submarine, airplane, and helicopter; plus a small number of army vehicles and manpacks. While these numbers may seem fairly large, full system-wide integration was essential for DOD to have any chance of recouping some of the system's costs.

Although these installations represent fairly obvious uses, some segments of the military had more ambitious plans for the system. Since the development of the GPS concept in the early 1970's, weapon designers had investigated the possibility of integrating the positional accuracy of GPS into short-range tactical missiles. Commanders were excited about the system's potential, but were reluctant to tie the lethality of their weapons into a system which could potentially be jammed, shot down, and whose accuracy (15-20 meters) wasn't as good as active terminally homing weapons.[18] Few of these initial efforts survived past the technology demonstration phase.

For DOD, the potential benefits of GPS went far beyond mere vehicle guidance. They were commencing development of a system for which the majority of the potential uses were as yet unknown. Reporting on the military potential of GPS, the Institute for Defense Analysis said "Most of the interesting new applications for GPS are in an embryo stage at present, and it may take 10 to 15 years to bring them to fruition."[19] It would be difficult to imagine a more prophetic statement.

Notes

[1] Comptroller General of the United States, *Report to the Congress: The NAVSTAR Global Positioning System—A Program with Cost and Benefit Uncertainties*, (Washington, D.C.: General Accounting Office, 1979), 1.

[2] Stefan Geisenheyner, "Navstar: A Man-made Celestial Constellation," *Asian Defence Journal*, December 1983, 58.

[3] See Appendix B for a description of the system's operation.

[4] Quoted in Geisenheyner, 58.

[5] Col Daniel K. Malone, "GPS/NAVSTAR," *Military Review*, March 1988, 37.

[6] Carl von Clausewitz, *On War*, ed. And trans. Michael Howard and Peter Paret (Princeton, N.J.: Princeton University Press, 1976), 119.

[7] Malone, 42.

[8] Geisenheyner, 62.

[9] Quoted in Geisenheyner, 62.

[10] James B. Schultz, "Navstar GPS Offers Mid-Course Guidance Improvements to Cruise Missiles," *Defense Electronics*, May 1984, 70.

[11] Comptroller General, 6.

[12] Institute for Defense Analysis, 89.

[13] Ibid., 80.

[14] Comptroller General, 7.

[15] Ibid., 7.

[16] Institute for Defense Analysis, 83.

[17] Comptroller General, 9.

[18] Schultz, 66-69.

[19] Institute for Defense Analysis, 9.

Chapter 3

Granting of Commercial Access

> *....the President has determined that the United States is prepared to make available to civilian aircraft the facilities of its Global Positioning System when it becomes operational in 1988.*
>
> —1983 White House press release

This statement, made in the wake of the 1983 Korean Air Lines Flight 007 shootdown by Soviet fighter aircraft, is widely touted as the beginning of GPS' civil role. Congress eagerly lent its support, passing Senate Resolution 69 and House Resolution 190 resolving "that the GPS is to be expedited for use in the civilian sector."[1] These citations represent the first proclamations of the civil availability of GPS.

With civilian access thus ordained, GPS became the most recent addition to a long list of military navigational systems widely adopted by the civil community, of which TRANSIT provides perhaps the most pertinent example.[2] Developed mainly to allow the Navy's Poseidon missile submarines to get an updated position fix prior to launch, TRANSIT represented an revolutionary improvement in open-ocean navigational accuracy that civil users were eager to have. Indeed, the system's designers had coded the signals to prevent unauthorized use. But in 1967, only two years after becoming operational, civilian pressure led to the release of the codes.[3] Sixteen years later, on the eve of the

similar announcement regarding GPS, TRANSIT had nearly 39,000 users—but only 800 were military.[4]

Had civilian pressure similarly "stolen" GPS? Hardly. DOD had always planned to allow civilians access to the system. In a 1973 Air War College paper, Lt. Col. Ronald L. Violette, a former Project 621B staff member, advocated civilian use of the system in detail, writing "We may (also) find that the best approach is to satisfy the civil and military needs with one system."[5] Comparing GPS to the TRANSIT experience, retired Army Colonel Daniel K. Malone wrote: "GPS designers were smarter. There are two codes."[6] Indeed, the very existence of the two codes is evidence of DOD's intentions to grant civil access, but only on its terms.

While the 1983 Reagan decision is widely credited as the origin of civil GPS, the reality is that such plans had been in place for years. A 1978 General Accounting Office (GAO) study initiated substantial Congressional interest, concluding that GPS could "replace many navigation systems at substantial savings" and concluded that many of the Department of Transportation's (DOT) navigational systems would be "unneeded" by the early 1990's.[7] The study also concluded that "strong navigation management at the executive level of the President was needed to overcome agency parochialism and to develop and carry out a Government-wide plan for navigation."[8] GAO had clearly embraced the system's promise of cost reduction.

Following the GAO study, Congress passed the International Maritime Satellite Telecommunications Act of 1978. Section 507(a) directed that:

> The President, in conjunction with Government agencies which will or may be affected by the development of a Government-wide radio navigation plan, shall conduct a study of all Government radio navigation systems to

> determine the most effective manner of reducing the proliferation and overlap of such systems. The objective of such study shall be the development of such a plan.[9]

The intent of the legislation was to force DOD and DOT to "review their navigation needs and to select a mix of common-use systems that would meet requirements for accuracy, reliability, coverage and cost while minimizing duplication of services."[10] Congress also was enamored with the cost savings promised by GPS.

Although initial deadlines were missed, the first Federal Radionavigation Plan, jointly signed by the Secretaries of Defense and Transportation, was published on 6 January 1981. The plan decreed that in 1983, DOT and DOD would jointly make a preliminary decision on the best future mix of radio-navigational systems. From 1983 to 1986, that decision would be coordinated and reviewed with affected groups leading to the issuance of a final decision in 1986. This process was, officially, to decide the future of civil GPS and the likely termination of numerous other systems.

While it appears that the 1983 Reagan statement bypassed the declared process, DOD had already published a somewhat obscure announcement describing a policy to allow civil access. In April of 1981, more than two years prior to the Presidential statement, the Secretary of Defense published a notice in the Federal Register:

> The latest DOD policy concerning NAVSTAR GPS is that when the system is declared operational, the highest possible level of C/A signal accuracy will be made available to the worldwide civil/commercial community within the limits of national security considerations. It is projected that this will be an accuracy of 200M Spherical Error Probable (SEP). This level of accuracy will be reviewed by DOD annually and the level modified to accommodate any changes commensurate with our national security posture. It is anticipated that this non-military accuracy may be increased as time passes.[11]

Although the system was not expected to become operational until 1988, it is clear that a decision allowing civil GPS usage had already been agreed upon as early as mid-1981.

Announced in response to the KAL 007 tragedy, the Reagan decision represented a opportunity to score diplomatic points in the cold war competition with the Soviets. It is apparent, however, that the decision merely announced, with great aplomb, what was already a "done deal." Regardless of the motivation, the deed was done—civil GPS was born.

Major Beneficiaries of Civil Access

The decision to grant GPS access to civil users benefited several groups, foremost of these being the GPS industry. The access decision immediately opened up an enormous market for GPS equipment. Additionally, the initial consumer demand required little investment in research and development, as most of the necessary technology had already been developed for the military program. Only later would civil users demand features equal or beyond that required by military users.

For some manufacturers shut out of the military programs through contract competitions, civil access provided a large market in which to recoup sunk costs, if not profit from the technology. In 1985, DOD selected Rockwell Collins as the prime contractor for initial receiver procurement. The contract, worth $450 million over five years, was for 4,300 receivers, and virtually shut other competitors out of the market.[12] Despite Collins' control of the US military market, nearly 100 companies were marketing GPS equipment by 1991, with fewer than 10 involved in military sales.[13] Clearly, the civil market created tremendous opportunities for manufacturers.

Civil access also benefited domestic manufacturers by dissuading foreign competition. While the US was putting GPS in orbit, the Soviet Union was building their own, very similar system called Glonass. The Soviet's system is suspiciously similar to GPS, with nearly identical orbits, frequencies, and keying techniques.[14] Dr. James Spilker, President of Stanford Telecommunication, suggested the Soviets "borrowed heavily" from the GPS program: "They must have paid close attention to the papers that we presented at the satellite navigation conferences..."[15]

The Soviets, however, made no attempt to prevent civil use of their system. Thus, continued US attempts to deny civil access had the potential to force civil users to turn away from GPS, and toward Glonass. For manufacturers committed to selling GPS-based equipment, such a move might have been economically disastrous. One US manufacturer, Magnavox, elected to build combination GPS-Glonass receivers for the civil market.[16] Fortunately for GPS manufacturers, with the GPS system offering slightly greater accuracy, more assured availability, and greater signal reliability, Glonass became a weak second choice.

Another group of beneficiaries, somewhat to DOD's dismay, were foreign militaries. While DOD encouraged sales of Precise Positioning Service (PPS) capable receivers to NATO and selected allied nations,[17] numerous other militaries have embraced the limited capabilities offered by civil receivers, further detailed in Appendix B. With Standard Positioning Service (SPS) equipment export no longer restricted,[18] manufacturers have found some of their best customers in foreign military organizations. Magnavox alone has sold SPS equipment to over 60 different military forces.[19] In 1991, Trimble Navigation's Vice President for Military Programs commented:

> We only sell to traditional allies and haven't had any requests to sell to anybody else. Technically, we're not prohibited from selling (SPS systems) to the Soviet Union, although they haven't approached us and we haven't approached them. We also haven't approached the Eastern European Market, although perhaps we should.[20]

Foreign militaries, well aware of the SPS limitations and the potential for further US degradation, are fully adopting civil GPS technology. Despite its limited accuracy, SPS still provides a major improvement over other navigational systems.

The most obvious beneficiaries were the civil users themselves. While the civil market has only existed for 14 years, the growth both in sales and in applications has been exponential. In 1984, the first civil receiver offered retailed for $150,000 and required two men to carry it. Ten years later, civil GPS receivers outnumbered military receivers by 10 to 1,[21] and a multi-channel handheld unit could be purchased for under $150. In a 1996 speech, Transportation Secretary Frederico Pena claimed "Most people don't know what GPS is. Five years from now, Americans won't know how we ever lived without it."[22] The benefits for civil users have only begun to be recognized.

The US taxpayer is another major beneficiary. Civil usage of GPS, in addition to the indirect savings created through increased efficiencies in numerous methods of transportation and communications, will directly save taxpayer funds through the elimination of redundant navigational systems such as OMEGA, TRANSIT and LORAN-C.[23] Without civil access to the Global Positioning System, DOT would be required to maintain operation of these systems at substantial taxpayer expense.

The Threat

Allowing civil users access to GPS is not without a downside. The major drawback of unrestricted civil access is that the navigational accuracy provided by GPS signals, in the wrong hands, can pose a substantial threat to national security. GPS technology could provide hostile forces, state and non-state, with low-cost precision weapon capabilities. It is this concern driving the fight against unlimited civil access.

Foreign militaries are not only purchasing the technology, they are producing it. Bharat Electronics, in cooperation with Indian government agencies, is producing a complete line of SPS capable units. Armscor and Barcom Electronics, in collaboration with the South African Army, are also producing military-specific units.[24] These are but two examples of production by non-aligned nations.

Does increased navigational accuracy in the hands of a potentially hostile force pose a threat to national security? The answer, of course, depends on how that capability is used. For land warfare, the addition of GPS capability can enhance combat effectiveness through improved self-location for launching platforms (artillery, rocket launchers, etc.), improved inter-unit coordination, greater maneuver rates, and more accurate target location. Realizing these benefits requires more than just a few GPS receivers—it requires forces with the proper equipment *and* training to properly use the receivers. Many of the world militaries do not possess these capabilities.[25]

It is unlikely that GPS will allow manned aircraft to pose any increased threat to US forces, particularly in the face of US air superiority capabilities. Similarly, a RAND study determined that GPS capability could only improve the accuracy of a Scud-type missile by about 20 percent.[26] Fortunately, export of GPS equipment capable of handling the

velocities and accelerations typical of ballistic missile profiles is restricted by the Missile Technology Control Regime.[27]

Unfortunately, GPS guidance does possess the potential to dramatically improve cruise missile guidance capabilities. Cruise missiles have traditionally used Inertial Navigation Units (INUs) for guidance, accumulating measurement errors (drift) directly related to time of flight. These errors, in most instances, have been severe enough to limit capability to all but short-range missions. GPS guidance, with constant error regardless of range, easily eliminates such problems. The threat posed by these missiles, however, is dependent upon more than just guidance. Even with accurate guidance, a missile must have sufficient range, payload, and defense penetration ability to pose a credible threat to US forces.[28]

The proliferation of GPS technology through civil access has contributed to an additional threat to US force capabilities—jamming. With US precision and delivery vehicles increasingly more dependent upon its guidance, the potential ability to jam GPS receivers presents a distinct concern. At the 1994 Precision Strike Technology Symposium, Magnavox's director of Tactical Data Systems, David Lewis, displayed a pair of homemade GPS jammers. Built from inexpensive commercially available components, the jammers were not much bigger than a cigarette pack, and produced only 100 milliwatts of output power; yet he claimed they were capable of jamming "every C/A code GPS receiver within a 10-mile radius."[29] He further stated that a 100-watt jammer could prevent initial signal acquisition for a standard military receiver within 600 nm (or line of sight, whichever is less) or cause the same receiver to break track within 28 nm.

Unfortunately, Mr. Lewis was right. The power level of GPS signals arriving from 10,900 nm above the earth's surface is 5 X 10^{-17} watts.[30] Referring to these power levels, Colonel Mike Wiedemer, then system director of the GPS Joint Program Office, said "they're about in the neighborhood of one-thousandth as strong as a low-power FM station, which means that brute force jamming—as usual with any radio signal—can have a detrimental effect on reception."[31] Although PPS-capable receivers are already much more difficult to jam than SPS units, efforts are ongoing to improve the resistance of military receivers to jamming, with improvements in antenna design, filters, and nulling techniques promising to provide up to 90 dB of jam resistance. This increased performance would require a 100-watt jammer within 0.3 nm in order to cause the receiver to break track.[32]

Another potential threat comes from "spoofing," or deceiving the GPS receiver vice blinding it with jamming. While this could significantly hamper military operations and targeting, imagine the potential disaster should a terrorist group discover how to "seduce" a GPS-guided 747 into flying into the ground. Fortunately, spoofing a PPS-capable receiver is extremely difficult, if not impossible, due to signal encryption. SPS receivers are slightly easier to spoof, although still extremely difficult, especially when combined with inertial navigation units.[33] Such capability is hopefully beyond the reach of any potentially hostile forces.

With the benefits of civil access come threats, admittedly some more serious than others. DOD recognizes the potential threats posed and is working to negate them. In 1995, Colonel Weidemer of the GPS Joint Program Office stated:

> GPS is probably in the same state of maturity that radar was in the 1940's. We have several programs to increase the security and improve the resistance to jamming and spoofing, as well as to deny our adversaries the capability to use the system in wartime. These efforts include improvements to antennas, interface electronics, filters and the basic receivers themselves, as well as developing technologies that will deny signals to adversaries. [34]

With the ability to diminish the various threats created through civil access improving, the promises of GPS approach realization.

The Big Winner

The major beneficiary of civil access to GPS was, arguably, DOD itself. Without civil access, it is entirely possible that the cost of GPS would have been too high. The 1975 Institute for Defense Analysis (IDA) study was tasked with identifying potential cost savings from both a Limited Operational Capability (LOC—initially 12 satellites) and the proposed deployment of Full Operational Capability (FOC—24 satellites) by 1984. In assessing the costs involved, the study concluded:

> Under the most optimistic assumptions (i.e., lowest GPS costs and the saving of all identified sources of cost avoidance), the break-even time for the FOC option is significantly greater (about 25 years) than the LOC option. This difference results from the much higher GPS costs and the relatively small additional cost avoidance from the landing aids and bomb/nav radars. If the high end of the GPS cost ranges were to apply, then GPS operations costs would become greater than the potential savings in the operational costs of current systems, and break-even points would cease to exist.[35]

Despite any potential increase in military utility, the ability of GPS to produce significant cost savings was crucial to the program's survival.

A 1973 Air War College research paper by Lt Col Ronald L. Violette, a former member of the Project 621B team, detailed the tense financial pressures facing the program:

> Pressure to reduce the defense budget continues to grow in spite of the fact that defense spending for fiscal year 1973, in dollars of constant buying power, is expected to be at its lowest level since 1951. . . . It appears that defense spending will fall under very close scrutiny from many fronts and demands for reducing manpower, cutting research and development (R&D), and dropping proposed new weapon systems programs will continue.[36]

With budget axes waiting to fall, the promised cost savings of GPS became even more important to the program's continued existence.

The IDA study determined that a substantial portion of the system costs would be involved in development and procurement of user system components (receivers). The authors acknowledged DOD's proposal to purchase approximately 23,000 units, predicting an average cost of approximately $25,000 per unit (1975 dollars). However, in examining the potential leverage offered by the rapidly developing field of microelectronics, they suggested that the average cost could be reduced to approximately $7,000 per unit. The problem was that this approach would require purchasing nearly 100,000 units to distribute the high initial fixed costs associated with the technology. Their proposed solution was to create additional requirements for receivers by extending implementation into the ground forces.[37] The study did not consider the cost reduction potential offered by civil access.

As predicted, microelectronics did come into play, with savings in 1985 of up to 62 percent over 1979 DOD goals.[38] More recently, in a 1993 contract with Rockwell Collins, DOD purchased 13,999 Precision Lightweight GPS Receivers (PLGR) for $21.9

million, or just under $1565 per unit.[39] A large portion of these cost savings were directly attributable to the economies of scale created though extending the GPS sales into the civil market.

Additionally, DOD has benefited through the increased capacity in the GPS industry resulting from civilian production. In late 1990, with the Gulf War looming, DOD found itself critically short of GPS receivers. Over 10,000 commercial units were hastily purchased from Trimble and Magellan Navigation, a purchase possible only because of civil access to the system.[40] With the war underway, DOD turned off "selective availability" and the commercial receivers yielded accuracy nearly equivalent to military PPS units.

The decision to grant civil access unquestionably benefited a multitude of users, but most importantly, it has benefited users within the Department of Defense. While decreased costs to DOD are certainly worthwhile, the true value of this leverage has been recognized in the military's ability to implement receivers throughout the force, making today's soldiers both more lethal and more survivable on the battlefield. Such is the legacy of commercial GPS.

Notes

[1] "Satellite-Directed Navigational Guidance for Aircraft," *House of Representatives, 98th Congress, 1st Session, Report Number 98-510:* 5.

[2] The majority of the original ILS and VOR ground systems in use in the U.S. were surplus military equipment from the end of WWII. TACAN technology, developed by the military, was widely copied in the civilian DME system. LORAN-C was developed by the Navy, yet in 1983 there were 400 Navy receivers versus 60,000 civilian receivers. The Navy's OMEGA system found its most widespread use in civilian airlines. Source: Peter K. Blair, "NAVSTAR, A European Review," *Signal*, February 1983, 33.

[3] Pace et al., 238.

[4] Blair, 33.

Notes

[5] Lt Col Ronald L. Violette, "A Global Navigation System: Ready But Waiting," Report no. 5098 (Maxwell AFB, AL, Air War College, 1973), 14-16.

[6] Col Daniel K. Malone, "GPS/NAVSTAR," *Military Review*, March 1988, 41.

[7] General Accounting Office, *Report to the Secretary of Transportation: DoT Should Terminate Further LORAN-C Development and Modernization and Exploit the Potential of the NAVSTAR / Global Positioning System* (Washington, D.C.: General Accounting Office, 1981), I.

[8] Ibid., 1-2.

[9] *International Maritime Satellite Telecommunications Act of 1978*, Public Law 95-564, 95th Cong., 2nd sess., (1 November 1978), 507, microfiche.

[10] Pace et al., 256.

[11] Department of Defense, Office of the Secretary, Notice, "NAVSTAR GPS Navigation Satellite Systems Status," *Federal Register* 46, no. 66 (7 April 1981): 20724, microfilm.

[12] Mark Hewish, "Multiple Uses of GPS," *International Defense Review* (Defense '95 Issue), 145.

[13] "Getting a Fix on the Market", *Jane's Defence Weekly*, 16 November 1991, 951.

[14] Christopher H. Clarke, "...and a Star to Steer By," *Defense Electronics* (June 1989), 64.

[15] Quoted in Clarke, 64.

[16] "Getting a Fix on the Market," 956

[17] Specifically: Australia, Belgium, Canada, Denmark, France, Germany, Italy, the Netherlands, Norway, Spain, and the United Kingdom, plus other US-allied countries "provided a US-approved PPS Security Module (PPS-SM) and an Auxiliary Output Chip (AOC), if appropriate, are used." Said governments must first negotiate appropriate security MOA's with the US DOD. Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 6130.01, *CJCS Master Navigation Plan*, 20 May 1994. Note: Various other sources list Israel, Japan, New Zealand, Portugal, and Turkey as having signed an MOU providing PPS access.

[18] Prior to 1991, most GPS exports require individual validated licenses to comply with Department of Commerce (DOC) export controls. On 1 September 1991, the DOC revised its electronic equipment export control list, essentially delineating between civil and military GPS equipment, and allowing civil receivers to be shipped "without restriction." Pace et al., 250.

[19] John F. Morton, "GPS Manufacturers See Opportunities in Pacific Rim," *Asian Defence Journal*, December 1992, 53.

[20] Walt Melton, quoted in "Getting a Fix on the Market," *Jane's Defence Weekly*, 16 November 1991, 952.

[21] Jennifer Ouellette, "GPS Industry Prepares for Boom," *Physics Today—The Industrial Physicist* (1995), 8.

[22] Statement by the Assistant Secretary for Public Affairs, US Department of Transportation, "Vice President Gore, Transportation Secretary Pena Usher In New Era for Travel, Time Savings, and Communications with Global Positioning Satellite System,"

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29 March 1996, n.p.; on-line, Internet, 10 Oct 1996, available from http://www.dot.gov/affairs/index.htm

[23] In 1993, the Federal Aviation Administration elected to cancel the Microwave Landing System, a replacement for the aging Instrument Landing System, for which they had expected to spend $1.4 billion over several years. (Robert W. Moorman, "Delaying the GPS Promise," *Air Transport World*, September 1993, 40). Cancellation of the prototype contracts alone saved $140 million dollars. (Phillip J. Klass, "FAA Cancels MLS in Favor of GPS," *Aviation Week and Space Technology*, 13 June 1994, 33). TRANSIT service terminated on 31 December 1996. ("Transit: An American Classic is Retired," *Johns-Hopkins University Applied Physics Laboratory Homepage*, n.p.; on-line, Internet, 19 February 1997, available from http://sd-www.jhuapl.edu/internal/TestPages/Transit/TaskS.html). The OMEGA navigation system is scheduled to cease operation as of 30 September 1997. (Department of Transportation, Notice of Intent, "Omega Radionavigation System Termination," *Federal Register* 61, no. 199, 11 October 1996; *Federal Register Online*, Internet, 09 February 1997, available from http://www.dot.gov/dotinfo/uscg/hq/g-m/nmc/regs/omega.htm). The 1994 Federal Radionavigation Plan, citing the likely decrease in usage due to GPS implementation, projects the shutdown of LORAN-C in the year 2000. While not yet shut down, the savings are already being realized as the Coast Guard was able to suspend its equipment recapitalization program. (Department of Defense and Department of Transportation, *1994 Federal Radionavigation Plan*, Springfield, VA; National Technical Information Center, 3-11).

[24] Mark Hewish and J.R. Wilson, "GPS Meets New Challenges," *International Defense Review* (October 1995), 57.

[25] Irving Lachow, "The GPS Dilemma: Balancing Military Risks and Economic Benefits," *International Security* 20, no. 1 (Summer 1995): 133-134.

[26] The study determined that the Scud and NoDong accuracy problems are dominated by reentry effect and cutoff control errors, and that velocity measurement errors were minute in comparison. For an in-depth discussion, see Scott Pace et al., "The Global Positioning System: Assessing National Policies (Santa Monica, CA: RAND, 1995), 57-69.

[27] Lachow, 137.

[28] Lachow, 135-136.

[29] John G. Roos, "A Pair of Achilles' Heels," *Armed Forces Journal* (November 1994), 21.

[30] Gerald Frost, *Operational Issues for GPS-Aided Precision Guided Weapons*, (Santa Monica, CA: RAND, 1994), 36.

[31] Quoted in Stephen M. Hardy, "Will the GPS Lose Its Way?" *Journal of Electronic Defense* (September 1995), 56.

[32] Roos, 22.

[33] Frost, 27-33.

[34] Hewish and Wilson, 57.

Notes

[35] Institute for Defense Analysis, *Impact of NAVSTAR Global Positioning System on Military Plans for Navigation and Position Fixing System* (Arlington, VA.: IDA, 1975), 8.

[36] Violette, 1-2.

[37] Institute for Defense Analysis, 105-119.

[38] Chris Bulloch, "Navstar Moves Ahead...But Will Geostar Outshine It?," *Interavia* (December 1985), 1368.

[39] Mark Tapscott, "Extending GPS on Land, Sea, and Air," *Defense Electronics*, (July 1993): 43.

[40] Pace et al., 245.

Chapter 4

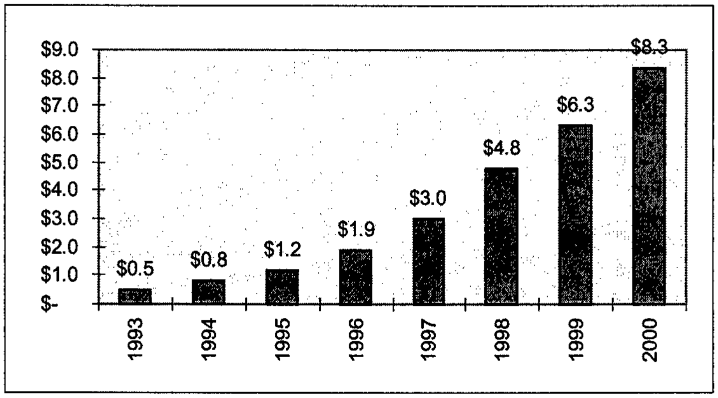
Growth of Commercial Usage

We are harnessing power in the sky to chart a prosperous new course on the ground.

—Vice President Al Gore

Although it might seem that the 1983 Reagan decision would have unleashed a pent-up flood of demand for civil user equipment, in actuality the civil market got off to a slow start. Partially due to the initial high cost and cumbersome size of user equipment,[1] the slow start was also attributable to the delays in system completion. Originally scheduled for completion in 1984, Initial Operational Capability was finally declared in December 1993.[2] These delays, however, did little to dampen the ultimate civil demand for GPS technology.

Despite the slow start, the market for civil receivers has grown exponentially since 1989. With advances in micro-electronics reducing size and unit cost, sales have expanded into market segments previously inaccessible. Annual sales, shown in figure 1, were only $85 million in 1990; the US GPS Industry Council predicts they will top $8.3 billion in the year 2000. Military purchases are expected to comprise less than 3 percent of these sales.[3]



Source: GPS Industry Council, in Pace et al., 104.

Figure 1. Global GPS Market Projections (billions of $)

Reduced size and cost are only partially responsible for the boom in GPS sales. Governmental agency approval for equipment use within the national air and maritime systems has contributed greatly to demand. In 1993, the Federal Aviation Administration (FAA) established the first standards for civil aviation GPS receivers, and by 1994, manufacturers were producing them.[4] Similarly, the Coast Guard has embraced GPS receivers for maritime use.

Additional factors have contributed to the dramatic sales increases. Manufacturers have made great strides in increasing revenues through innovative application of the technology, implementing GPS receivers in revolutionary ways. While accurate positional data alone has value to some segments of the market, the true appeal of GPS to consumers is being seen in applications where GPS capabilities are embedded to enhance overall product performance.

Civil applications of GPS have gone far beyond the wildest concepts of the system's designers. With accurate positional data just a small part of today's civil applications, tomorrow's uses of GPS are certain to be even more revolutionary. Indeed, it is the civil

adaptation of the technology that has proven to be the industry's force for innovation, in both civil and military applications.

Notes

[1] The first commercial unit cost $150,000 and required two men to carry. Jennifer Ouellette, "GPS Industry Prepares for Boom," *Physics Today—The Industrial Physicist* (1995), 8.

[2] Initial Operational Capability meant the system was capable of sustaining continuous worldwide SPS coverage. Scott Pace et al., *The Global Positioning System: Assessing National Policies* (Santa Monica, CA: RAND, 1995), 246.

[3] Bruce D. Nordwall, "RAND Recommends Military Control GPS," *Aviation Week and Space Technology* (12 February 1996), 45.

[4] James P. White, "Swords and Plowshares: The Dual-Use Role of the Global Positioning System," *Defense Electronics* (May 1994), 17.

Chapter 5

Selective Availability

On 25 March 1990, in accordance with the current Federal Radionavigation Plan and with Initial Operational Capability looming on the horizon, the Department of Defense activated "selective availability" (S/A) for the first time.[1] This purposeful degradation of the SPS signals was intended to implement DOD's stated policy of allowing only 100-meter accuracy from SPS service. DOD's justification of the degradation was "that civilian users do not require increased accuracies and that such a move would increase the accuracy of hostile weapons using GPS."[2] Civil users disputed these points, but with little effect.

DOD's policy with respect to SPS signals is outlined in the CJCS Master Navigation Plan. Regarding GPS security policy, the plan states:

> SPS is available to all, on a worldwide basis with no direct fee. SPS provides 100 meter, or better, horizontal positioning accuracy (95 percent probability) and timing accuracy within 340 nanoseconds (95 percent) of universal time coordinated (UTC, US Naval Observatory). These accuracies will be provided at all times except during national crises. Timing accuracies will not be guaranteed. *The decision to alter SPS specifications will be made by the NCA.*[3] (Emphasis added)

In countering arguments that S/A should be turned off in peacetime and activated only when hostilities appear imminent, DOD argues that once civil users become dependent on

the increased accuracy, obtaining authorization from the President to reactivate it will be extremely difficult.

The Civil Response

While most recreational users do not, indeed, need precise accuracies from GPS, there are certain users who do require such precision. Denied such capabilities by S/A, these users have attempted to negate its effects through *differential* GPS (DGPS).[4] While such techniques were considered by the military as early as 1975 to allow GPS-guided precision approaches for military aircraft,[5] differential GPS was first used in the civil marketplace. In the late 1980's, with coverage from the few orbiting satellites limited at best, surveyors first used differential techniques to extend the system's availability. Since then, differential GPS has proven to be an effective way to increase the accuracy of civil signals.

Sensing potential profit, companies have begun providing differential corrections to paying subscribers. One such organization, John E. Chance and Associates, has been transmitting GPS corrections from its ten US reference stations through a company-owned transponder on a GTE satellite. A spokesman for the company claims the horizontal accuracy for a moving receiver is approximately 40 cm.[6] Chance and Associates is but one of numerous companies providing similar services worldwide.

In what might appear to be a major miscalculation, elements of the Department of Transportation are also entering the DGPS business. A DGPS system deployed by the Coast Guard was declared operation in January of 1996.[7] The Maritime DGPS system

was designed to provide accuracy greater than 10-meters for all US harbor and harbor approach areas. Prototype systems demonstrated accuracies close to 1-meter.[8]

The Federal Aviation Administration is also planning to develop a DGPS system. The Aeronautical GPS Wide Area Augmentation System (WAAS) is intended to support enroute through precision-approach navigation by providing differential corrections, a ranging capability, and most importantly, integrity data on the various GPS signals. Scheduled to deploy in phases, initial operational capability is planned for 1997 with final capability to be attained in 2001. The FAA expects to certify GPS WAAS precision approaches beginning in 1997, and expects 8000 precision approaches to be available by 2001.[9] Published estimate for WAAS accuracy cite 15 meters,[10] yet this is insufficient for precision approach usage.[11]

It may appear dysfunctional for one Federal agency (DOD) to demand S/A while another agency (DOT) provides differential systems to defeat it. In some ways it probably is. Differential GPS equipment, however, is already in use throughout the world; it is in the best interest of the United States to be able to exercise control over these types of systems. By creating systems that provide this type of coverage over US territory and providing the services without charge, potential commercial providers of such services will be dissuaded. With differential systems under direct US control, denial of such signals in times of crisis is facilitated.[12]

DOD has other reasons for acquiescing to the development of government DGPS systems. If these systems will be capable of providing enroute and approach phase navigation for aviation and maritime use, DOD wants to use them also. According to Col Wiedemer of the Joint Program Office, "We would like to capture some of the other

functions that will be offered by the civilian community. For example, if we can get differential GPS and an ability to receive the WAAS signal and process its integrity messages at the same time, we'd like to do that."[13]

While DGPS systems likely increase the threat to US national interests, DOD is taking steps to reduce their effect. Discussing DGPS systems, the CJCS Master Navigation Plan states:

> DOD recognizes that there is currently extensive civil interest in differential GPS and that the US private sector may apply to the Federal Communications Commission (FCC) for licenses to establish and operate differential GPS transmitters. DOD will, therefore, institute measures to ensure that all appropriately licensed differential GPS operations that are under US control are terminated if necessary in times of national emergency when the war powers of the President are implemented under section 706 of the Communications Act of 1934 as amended. The United States will also recommend that allied nations that use GPS consider similar controls. CJCS MOP 30 procedures will be considered in case of non-cooperation and continued use of differential GPS. US forces will develop means and tactics to destroy or spoof unfriendly differential GPS in combat zones.[14]

Additionally, commercial local area differential systems are potentially less threatening than wide area systems due to the varying equipment requirements and subscription fees.

It is interesting to consider that the driving force behind the development of differential GPS capabilities has been DOD's implementation of S/A. Without S/A, there would have been little demand for GPS corrections. Said one industry source:

> DOD would have been better to have either given commercial users such a bad signal that the system would never have become popular or to have simply given them the same 25-meter resolution and apply S/A during wartime. This way, the DOD had people putting money into countermeasures early on."[15]

Unfortunately, this may be quite correct.

The Dispute

DOD argues that eliminating S/A poses a threat to national security interests, and insists that the degradation is essential to protect US forces from hostile weapons systems using GPS guidance. The irony of the argument is that, both in the 1991 Gulf War and in the 1994 Haitian operation, S/A was turned off so that US forces could use commercial receivers accurately. If S/A is so essential to the protection of US forces, why was it turned off when they were most likely to need it?[16]

Even with S/A deactivated, SPS accuracy is not equivalent to PPS accuracy. A 1993 joint DOD/DOT task force reported that elimination of S/A would yield SPS accuracies of 54 meters.[17] Other authors insist it would be much less. GPS World Magazine reported that during the Haitian operations, SPS signals (S/A off) "showed 10+ meter accuracy, 95 percent of the time; and 5-7 meter, 50 percent of the time. That was with the standard (C/A) code on L1, employing off-the-shelf receivers."[18]

While such potential accuracy would appear to justify DOD's assertions about non-degraded SPS posing a threat, others insist that the threat is minimal. In 1991, Bill Rhodes of Rockwell Collins, the corporation that built the majority of GPS satellites and US military user equipment, explained:

> The GPS system has been specifically structured to have both a military and commercial side. It is safe to assume anyone using a C/A-code for military purposes is doing so at their own risk and the US Government will not allow that to happen. There are a number of methods, including jamming, but it is well understood that the US Government will guarantee the enemies of the USA will not use the GPS for military purposes . . . it's something that the US Government is investigating and Rockwell is working on.[19]

Thus, even without S/A, an opponent would have to overcome other defenses in order to employ GPS-guided weapons against the US.

Oddly enough, these arguments may all be moot. On 29 March 1996, President Clinton signed a Presidential Decision Directive revising US GPS policy. Key to this new policy was an intent to remove Selective Availability:

> It is our intention to discontinue the use of GPS Selective Availability (SA) within a decade in a manner that allows adequate time and resources for our military forces to prepare fully for operations without SA. To support such a decision, affected departments and agencies will submit recommendations in accordance with the reporting requirements outlined in this policy.[20]

Accordingly, the policy requires that, beginning in the year 2000, the President make an annual "determination on continued use of GPS selective availability," based on advice from the heads of appropriate Federal agencies.[21] The argument is over; selective availability will be removed. It is just a question of when.

Notes

[1] Scott Pace et al., *The Global Positioning System: Assessing National Policies* (Santa Monica, CA: RAND, 1995), 264.

[2] Irving Lachow, "The GPS Dilemma: Balancing Military Risks and Economic Benefits," *International Security* 20, no. 1 (Summer 1995), 142-143.

[3] Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 6130.01, *CJCS Master Navigation Plan*, 20 May 1994, D-1.

[4] Differential GPS works by using a ground reference station. A point is first surveyed to great precision, then the differential reference station is located at that position. The reference station, consisting of a GPS receiver and a transmitter, measures its position according to the GPS signals it is receiving, and compares that position with its known position to determine the *bias error*. This error is then inverted to generate a *correction*. Since every receiver viewing the same satellites is subject to the same amount of error (particularly error induced by S/A), they are all "off" by the same amount and direction as the reference station. The reference station broadcasts the correction signal, sometimes on an additional frequency and sometimes on the C/A frequency itself (pretending to be yet another satellite), and the differential receiver calculates the corrected position. Accuracy available through differential techniques varies according to

Notes

the quality of the correction and equipment, but such stations are capable of providing sub-meter accuracy. (Pace et al., 128).

[5] Institute for Defense Analysis, *Impact of NAVSTAR Global Positioning System on Military Plans for Navigation and Position Fixing System* (Arlington, VA.: IDA, 1975), 20-21.

[6] Bruce D. Nordwall, "Growing Demand Boosts GPS Progress," *Aviation Week and Space Technology* (19 September 1994), 62.

[7] Transportation Secretary Frederico Pena, prepared statement at ceremonies declaring the Maritime DGPS system operational, Alexandria, VA., 30 January 1996, n.p.; on-line, Internet, 19 Feb 1997, available from http://www.dot.gov/affairs/gpssp.htm.

[8] Department of Defense and Department of Transportation, *1994 Federal Radionavigation Plan* (Springfield, VA, National Technical Information Center), 3-35.

[9] Federal Radionavigation Plan, 3-35,36.

[10] Bruce D. Nordwall, "GAO Questions Schedule for GPS Augmentation," *Aviation Week and Space Technology* (19 June 1995), 42.

[11] In order to obtain the described precision approach capability, the system must provide accuracies on the order of 5-meters to achieve even Category I precision approach capability. Attaining Category III capability will likely require local differential augmentation of some sort to achieve the mandated 1.2-meter specifications. (Edward H. Phillips, "D-GPS Systems Demonstrate Precision Autoland Capability," *Aviation Week and Space Technology*, 20 September 1995, 85.

[12] Pace et al., 85.

[13] Quoted in Mark Hewish and J.R. Wilson, "GPS Meets New Challenges," *International Defense Review* (October 1995), 58.

[14] *CJCS Master Navigation Plan*, D-8.

[15] Quoted in Holly Porteous, "GPS: Waiting for a Clear Signal," *Jane's Defence Weekly* (16 November 1991), 950.

[16] The answer, of course, is that in both cases, the opposing forces were considered incapable of employing GPS technology against US forces.

[17] Joint Department of Defense/Department of Transportation Task Force, *The Global Positioning System: Management and Operation of a Dual-Use System* (Washington, DC: December 1993), 30.

[18] Hale Montgomery, "Academies Study GPS; Federal Budget; GPS Collars Fish Poachers," *GPS World* (April 1995), 12.

[19] Quoted in Porteous, 949.

[20] Office of Science and Technology Policy, National Security Council, "US Global Positioning System Policy," 29 March 1996, 2, n.p.; on-line, internet, 11 February 1997, available from http://www.whitehouse,gov/WH/EOP/OSTP/html/gps-factsheet.html.

[21] Specifically DOD, DOT, CIA and "other appropriate departments and agencies." Ibid., 4.

Chapter 6

The Promise Fulfilled

Since the 1973 creation of the GPS Joint Program Office, the Department of Defense has invested over $8.1 billion in the Global Positioning System. While a portion of this figure likely would have been spent supporting other systems anyway, DOD has nonetheless made a substantial investment in the system, both in satellite and in user equipment costs. As with any other investment, at some point one expects a return. Has GPS fulfilled DOD's expectations?

Interestingly, several developments since the 1973 decision have actually increased the viability of GPS in terms of military utility. Foremost were the cost reductions facilitated by civil access. Secondly, the end of the Cold War and subsequent demise of the Soviet Union substantially contributed to the military's ability to rely on GPS. In the mid-1980's, Soviet forces presented a credible capability to destroy some or all of the GPS satellites during a conflict. Only with that threat substantially eliminated was the US military able to rely on GPS availability.[1]

GPS-Guided Munitions

GPS had always demonstrated the potential to be used in a weapons role. That potential, however, was limited by certain factors. Receiver cost and size reductions, both

through civil demand and through revolutionary advancements in electronics, made GPS-guided weapons possible, with the units primarily used for midcourse guidance. Such weapons could hit any designated latitude/longitude/altitude position a military commander cared to designate. For most tactical applications, however, this was insufficient. Only with the advent of sophisticated targeting radars did GPS-guided munitions become *tactically feasible*. Such radars made it possible to target more than just geographic coordinates.

Additionally, such weapons were adequate only to the extent they were not expected to function in a jamming environment. Advances in antennas, filters, and processing techniques provided meaningful increases in the jamming resistance threshold. Major reductions in cost and size of Inertial Navigation Units (INUs), along with increased precision, have also been crucial to this capability. Coupled to the GPS-guidance system of a weapon, these INU's provide increased spoof-resistance and the ability to continue targeting even after jamming has forced the GPS receiver to break track.[2]

While it is unlikely that GPS-guided munitions will totally replace terminally-homing precision munitions such as laser-guided bombs, GPS-guidance does provide some distinct advantages against fixed or stationary targets. Apart from their lower cost, GPS munitions are passive, are "fire and forget," and unlike laser-guided munitions, can function in any weather conditions.[3] GPS-guided munitions are not a replacement for other precision weapons; they merely represent another option for the military commander.

Implementation

Invigorated with the potential of this embryonic system, DOD's designers are incorporating its capabilities throughout the services. The original plan for GPS was to install receivers in every military ship and aircraft, with a few thousand receivers to be selectively distributed throughout the ground forces. Cost reductions in receivers have allowed DOD to substantially increase those quantities, having purchased over 75,000 receivers through the end of FY 95 with projected purchases through FY 2005 totaling nearly 100,000 additional units.[4] With numbers of this size, DOD must be installing these receivers in more than just ships and aircraft.

The large number of receiver purchases can be partially explained by DOD's effort to replace all of its commercial SPS receivers with military PPS systems. Unable to procure enough PPS receivers to meet units' demand, particularly with the Gulf War looming, the military purchased thousands of commercial SPS receivers, developing a C/A code dependency in the process. This "dependency" is the reason S/A was deactivated during the Gulf War and the Haitian operations.

Aware of this SPS vulnerability of its forces, DOD is making a dedicated effort to replace every military C/A-code unit with a PPS-capable receiver. With S/A destined to be permanently removed, US forces will be required to rely on GPS jamming or spoofing to deny hostile forces use of the signals. It is therefore essential that friendly forces are equipped with the jam-resistant PPS receivers, allowing them to continue operations in a GPS-denial environment. To this end, DOD executed the PLGR contract, procuring up to 94,000 PPS-capable units over four years.[5]

Additional receiver demand will result from several programs in development attempting to employ GPS in an embedded role, rather than just providing information on a navigational display. Objectives of these programs (detailed in Appendix C) include weapons guidance, downed aircrew location, hyperaccurate sensing, and improved battlefield command and control. These level-of-magnitude advances in the application of GPS technology are hardly something the designers of GPS might have foreseen, going well beyond any of DOD's initial expectations.

While some of these systems are operational, many of these are programs still in the developmental phase. These are expensive projects, but the military is committed to their completion. Were the senior leadership in DOD not convinced of the viability of GPS on the battlefield of the future, they would not willingly commit such a large amount of their increasingly scare resources to such programs.

Notes

[1] Gerald Frost, *Operational Issues for GPS-Aided Precision Guided Weapons*, (Santa Monica, CA: RAND, 1994), 1.

[2] Ibid., 9-19.

[3] Ibid., 2.

[4] Scott Pace et al., *The Global Positioning System: Assessing National Policies*, (Santa Monica, CA: RAND, 1995), 13.

[5] If all four options under the contract are exercised. The initial buy was for 13,999 units. Mark Tapscott, "Extending GPS on Land, Sea, and Air," *Defense Electronics* (July 1993), 43.

Chapter 7

Conclusions

The objective of this study was to trace the development of the GPS system and to assess the effects of commercialization on the military's ability to employ the system as originally envisioned. Does the system provide military users all they had originally envisioned? Did civilian usage compromise its military utility, or did it actually enhance its military role?

The evidence presented herein has conclusively demonstrated that commercialization has not been detrimental to DOD's realization of its GPS vision. In fact, GPS appears to have become more successful than anyone in DOD could have imagined, yielding applications which have only begun to be considered. That many of these applications have civil utility is unimportant; they do not detract or interfere with military usage.

The widespread distribution of GPS technology associated with civil usage may have contributed to an increased threat from jamming. Additionally, civilian pressure for improved accuracy has compromised DOD's ability to deny accurate navigational information to potentially hostile forces through selective availability. In these aspects, civil usage has been detrimental to the military's interests. But as evidenced herein, these are but minor irritations and easily overcome.

In actuality, the Global Positioning System likely would not have been possible without civil demand. The costs associated with the constructing the system and equipping the users would have been prohibitive. Had the system survived despite the monumental cost, it would certainly not be capable of providing the military utility its users enjoy today. DOD was well aware of this; they had planned for it from the start. Individual infantrymen hold GPS units today only because of civil demand and innovation. It is unquestionable that commercialization has served to enhance the system's military utility.

In the process of commercialization, however, DOD did lose a portion of their policy control over the system. With civil users outnumbering military users by ten to one, this had to be expected. DOD once exercised exclusive control over the system; the 1993 Joint DOD/DOT Task Force resulted in a 1994 policy-sharing arrangement whereby DOT became responsible for civil GPS policy.[1] Although DOD retains control over daily system operations, the military must accept that GPS policy decisions will be increasingly based on civil requirements.[2] This must be considered as a necessary tradeoff in return for benefits received.

While GPS was originally conceived as a military system, it represents the epitome of dual-use technology. Despite apparently conflicting demands, GPS is fully capable of serving two masters. With a climate of synergistic cooperation established between DOD and the civilian GPS sector, the system will continue to serve both, well into the 21st century.

Notes

[1] Scott Pace et al., *The Global Positioning System: Assessing National Policies*, (Santa Monica, CA: RAND, 1995), 253-255.

[2] The informal arrangement was made permanent in President Clinton's 1996 policy revision. Office of Science and Technology Policy, National Security Council, "US Global Positioning System Policy," 29 March 1996, 2, n.p.; on-line, Internet, 11 February 1997, available from http://www.whitehouse.gov/WH/EOP/OSTP/html/gps-factsheet.html.

Appendix A

The History of GPS

In the early 1960's, faced with a requirement for accurate launch fixing for Poseidon submarines, the US Navy launched seven satellites into low polar orbit. The satellites, broadcasting a highly stable radio signal, formed the basis of a two-dimensional navigation system known as TRANSIT. Although TRANSIT provided a revolutionary improvement in open-ocean navigation, providing positional accuracy within 200 meters,[1] it was not without limitations. The system had limited coverage, required long observations, and was suitable only for slow-moving platforms. It was entirely unsuitable for aviation use, and was tactically deficient in requiring prolonged observation at entirely predictable times. Thus, while TRANSIT constituted an enormous improvement over previous capabilities, researchers commenced development of a follow-on system.

The early 1970's found the Navy and the Air Force researching two separate satellite navigational systems: The Navy's system was known as TIMATION while the Air Force effort was titled Project 621B. Both programs were similarly attempting to employ precise satellite-transmitted time-sequenced signals for navigational purposes. On 17 April 1973, following the recommendations of a joint steering group,[2] the Deputy Secretary of Defense issued a memorandum directing integration of the two efforts into a single comprehensive program. With the Air Force designated as the lead service, a Joint

Program Office was established to combine the best concepts of each program into a NAVSTAR GPS system to satisfy the needs of all the services.[3]

On 17 July 1995, after twenty-two years and $8 billion, the Air Force Space Command formally declared that GPS had achieved Full Operational Capability (FOC).[4] The program had suffered its fair share of delays; it was originally planned to achieve FOC in 1984.[5] These delays included budgets that were zeroed out and restored, satellite failures, and delays due to the space shuttle *Challenger* disaster.

Amidst these delays and setbacks, and despite not having achieved even Initial Operating Capability,[6] the system made great contributions to US efforts during the Gulf War. Described by the commander of the 101st Airborne Division as "the most popular new piece of equipment in the desert,"[7] the partially completed system was able to provide 22.5 hours of two-dimensional and 16.75 hours of three-dimensional coverage per day.[8] It is entirely possible that the fabled "left-hook," out-flanking the entrenched Iraqi forces through featureless desert terrain, may only have been feasible because of GPS.

Notes

[1] Richard W. Blank, "The NAVSTAR Global Positioning System," *Signal*, November 1986, 76.

[2] Scott Pace et al., *The Global Positioning System: Assessing National Policies* (Santa Monica, CA: RAND, 1995), 240.

[3] Institute for Defense Analysis, *Impact of NAVSTAR Global Positioning System on Military Plans for Navigation and Position Fixing System* (Arlington, VA.: IDA, 1975), A-1.

[4] Pace et al., 246.

[5] "Satellite Navigation," *Countermeasures*, December/January 1975/1976, 7.

[6] Pace et al., 246.

[7] Lt Gen J.H. Binford Peay, quoted in Michael R. Rip, "How NAVSTAR Became Indispensable," *Air Force Magazine*, November 1993, 46.

[8] Michael R. Rip, "How NAVSTAR Became Indispensable," *Air Force Magazine*, November 1993, 46.

Appendix B

System Overview

The Global Positioning System consists of twenty-four nearly identical satellites (the "constellation") in high-altitude orbit and five ground stations. These satellites are spaced to ensure continuous global coverage. Each satellite is, in essence, a hyper-accurate atomic clock transmitting a repeating coded signal, consisting of its position and the current time. With four satellites in view, a receiver can determine the time delay of receipt, multiply by the speed of light to calculate the distance to each satellite, and thereby determine the user's position.

Each satellite actually transmits *two* coded signals: A Precision (or P-code) and a Coarse/Acquisition (or C/A-code). The P-code, designed for authorized users, is more accurate and more jam-resistant than the C/A code. Encrypted to prevent unauthorized use, the P-code is capable of providing 25 meter accuracy with a 95% probability; this is referred to as the Precise Positioning Service (PPS).[1] Only specially equipped receivers, loaded with the proper codes, can use PPS. Current US policy limits such access to US and certain allied militaries, some federal agencies, and certain specific organizations and companies.

The C/A code, designed for non-military users, was intended to be less accurate than the P-code information. Easier to acquire, it is also much easier to jam. Originally

intended to provide approximately 100 meter accuracy, actual performance in testing indicated 20-30 meter accuracy.[2] The Department of Defense, concerned over the threat such accuracy might pose to National Security, intentionally degrades the C/A signals through a feature called "selective availability." Selective availability introduces intentional error into the C/A signals, degrading accuracy to approximately 100 meters. C/A signals, referred to as the "Standard Positioning Service" (SPS), are available without charge to any user with a capable receiver. However, DOD reserves the right to further degrade or even deny the C/A signal in time of national crisis.

An additional feature of the system is the ability to provide users with a hyper-accurate time standard. Accurate to within 340 nanoseconds for civil use,[3] this feature provides numerous capabilities including enhanced coordination, time-stamping and data network switching.

Notes

[1] Irving Lachow, "The GPS Dillema: Balancing Military Risks and Economic Benefits," *International Security* 20, no.1 (Summer 1995): 128.

[2] Pace et al., 222.

[3] CJCS Instruction 6130.01, *CJCS Master Navigation Plan*, 20 May 1994, D-1.

Appendix C

Innovation in Military GPS Implementation

Several development programs are underway to realize the potential contribution of GPS for both weapons guidance and other military applications. The objective of these programs is to use GPS technology to provide more than just a latitude-longitude readout by embedding the GPS receiver into the system itself. Selected GPS-guided weapons systems in development include:

- GPS-Aided Targeting System (GATS) / GPS-Aided Munition (GAM)—Developed for use in the B-2 bomber, GATS is designed to employ the GAM until JDAM is available in 1999.[1]
- Miniature Integrated GPS/INS Tactical System (P-MIGITS)—This project couples a low-end inertial navigation unit with a GPS receiver to provide increased accuracy and jam resistance. This system has been successfully integrated into the AGM-130 air-to-ground missile.[2]
- Low-Cost Competent Munitions (LCCM)—An Army program attempting to use GPS guidance in an artillery round. Eventually this program will couple the guidance system with canards to steer the round to the desired impact location.[3]
- Navy's Guided 5-inch shell—A GPS-guided naval gunfire round designed to be fired from the Navy's workhorse 5-inch shipboard guns.[4]
- Joint Direct Attack Munition (JDAM)—This program will equip up to 74,000 conventional bombs with a GPS/INS steering and guidance package to achieve a 13-meter CEP.[5]
- Army Tactical Missile System (ATACMS)—A planned improvement to employ an integrated GPS/INS guidance package into the Army's primary deep strike weapons system.[6]
- Air-Launched Cruise Missile (ALCM-C)—Initially constructed as a B-52 launched strategic nuclear delivery vehicle, the modified cruise missile traded its nuclear payload and terrain contour guidance system for a 1000-lb conventional warhead and GPS guidance.[7]

- Tomahawk (TLAM)—Both the Block III and Block IV upgrades incorporate GPS/INS guidance as a replacement for the earlier terrain comparison guidance system.
- Standoff Land Attack Missile (SLAM)—Equipped with a IR-imaging terminal sensor, GPS is employed to provide mid-course guidance.
- Joint Standoff Weapon (JSOW)—This tri-service next-generation missile program also employs GPS to provide mid-course guidance.[8]

These are but a few examples of DOD's efforts to integrated GPS into weapons systems.

The military's most innovative GPS utilization efforts, however, have nothing to do with weapons guidance or navigation. For example, the GPS-112 Search and Rescue Handheld Transceiver integrates a six-channel SPS receiver within a handheld VHF/UHF transceiver for use by downed aircrews. Able to function as a stand alone navigational aid in an evasion situation, the radio transmits either voice or positional data to rescue aircraft in single bursts to dramatically lessen the probability of intercept.[9]

The Tidget GPS sensor represents another innovative application of GPS technology. Despite huge reductions in the cost of GPS receivers, installing them in "one-time use" applications can be prohibitively expensive. The Tidget sensor is intended to be a disposable device, priced under $75, for use in such applications. Embedded in a sonobuoy, radiosonde, or other disposable sensor, the Tidget "samples and digitizes the received GPS C/A code and transmits a compressed snapshot" at preset intervals to the monitoring aircraft or ground station, where the data is processed into positional information. The low cost is due to the lack of any processing capability in the sensor itself.[10]

Perhaps the most innovative application in development is the Situational Awareness Beacon with Reply (SABER) program. The SABER beacon, consisting of a GPS receiver, UHF transceiver and a computer, is intended to facilitate identification of friendly

forces. Using SATCOM or line-of-sight transmissions, the beacon transmits own unit identification, position, altitude, heading and velocity to any capable user in the SATCOM footprint. The receiving unit processes this information through a standard battlespace C^4ISR system such as JMCIS.[11] The receiving capability of the beacons also allows a user to poll any particular unit or groups of units, receiving a reply from the specified unit within two minutes.

The system's most amazing feature is a result of this polling capability. Similar to Mode IV IFF, the "Don't shoot me" feature allows for rapid battlefield query and identification. When a potential shooter "locks up" a target, the target designation equipment executes a handoff to the SABER beacon, transmitting an "intent to kill" message identifying the aimpoint and weapons-effect range. The beacon of any friendly unit within harm's way responds with a "don't shoot" message and its identifying data, which is transferred back to the target designation system. The whole evolution takes less than two seconds, yet has the potential to provide greater combat efficiency while simultaneously reducing fratricide.[12] This is hardly something the designers of GPS might have foreseen.

Notes

[1] Leigh Ann Klaus, "GPS Advancements Overshadow Growing Pains," *Defense Electronics* (February 1995), 14.

[2] Ibid., 13.

[3] Scott R. Gourley, "GPS: The Ultimate Dual-Use Technology?," *Defense Electronics* (August 1995), 18.

[4] Neil Munro, "The GPS Network: Everybody Wants a Slice," *Armed Forces Journal* (August 1994), 16.

[5] Mark Hewish, "Multiple Uses of GPS," *International Defense Review* (Defense 95 issue), 147.

[6] Munro, 16.

Notes

[7] Michael R. Rip, "How NAVSTAR Became Indispensable," *Air Force Magazine* (November 1993), 48.

[8] John G. Roos, "A Pair of Achilles' Heels," *Armed Forces Journal International* (November 1994), 22.

[9] Gourley, 17.

[10] Bruce D. Nordwall, "GPS Could Improve Sonobuoys, Radiosondes," *Aviation Week and Space Technology* (18 October 1993), 71-72.

[11] Joint Maritime Command Information System.

[12] Mark Hewish and J.R. Wilson, "GPS Meets New Challenges," *International Defense Review*, (October 1995), 60.

Glossary

CEP	Circular Error Probable
DOD	Department of Defense
DOT	Department of Transportation
FOC	Full Operational Capability
GAO	Government Accounting Office
GPS	Global Positioning System
IDA	Institute for Defense Analysis
IOC	Initial Operational Capability
IMU	Inertial Measurement Unit
JCS	Joint Chiefs of Staff
LOC	Limited Operational Capability
NCA	National Command Authority
PLGR	Precision Lightweight GPS Receiver
PPS	Precise Positioning Service
SEP	Spherical Error Probable
SPS	Standard Positioning Service
WAAS	Wide Area Augmentation System

C/A-code. The Coarse/Acquisition code designed for civil use. Broadcast in the clear, the code enables commercial receivers to achieve at least 100-meter accuracy.

Circular Error Probable. The radius of the circle within which there is a 50% probability of being located.

Glonass. The Soviet version of GPS.

NAVSTAR. Another name for the GPS system.

OMEGA. An electronic navigation aid with worldwide coverage. Scheduled to be terminated on 30 September 1997.

P-code. The precision code feature of GPS, encrypted to prevent access by unauthorized users. This feature allows military receivers to achieve 25-meter accuracy.

Precise Positioning Service. The GPS signal encrypted for military use. Employs the P-code and authorized receivers to achieve 25-meter accuracy.

Project 621B. An US Air Force project in the late 1960's to develop a satellite navigation system for airborne users.

Selective Availability. The DOD policy to deny precise accuracy to civil users by intentionally degrading the SPS signal.

Spherical Error Probable. The radius of the sphere within which there is a 50% probability of being located.

Standard Positioning Service. The GPS signal intended for civil use. Employing the C/A code broadcast by the GPS satellites, a SPS receiver is guaranteed by DOD to provide a position within 100 meters of actual location, 95 percent of the time.

TACAN. A short-range, radio-based aircraft navigation aid primarily used by military aircraft.

TIMATION. The Navy's concept for a satellite-based system to improve upon TRANSIT.

TRANSIT. The first satellite-based navigational system. Developed by the US Navy in the early 1960's, each satellite broadcast a highly stable radio signal which allowed position fixing with 200-meters. The system was terminated on 31 Dec 1996.

VOR/DME. A short-range, radio-based aircraft navigation aid primarily used by civil aircraft.

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